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COMMITTEE ON THE PEACEFUL USES OF OUTER SPACE

SATELLITE-BASED RADIO BROADCASTING

Note by the Secretariat

1. The Working Group of the Whole to Evaluate the Implementation of the Recommendations of the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE 82), at its eighth session (A/AC.105/571, annex II, para. 17), recommended that several studies on space applications should be carried out to demonstrate the potential of space technology. The Working Group of the Whole identified a number of possible subjects for such studies, including the use of satellite-based radio broadcasting services.
2. The report of the Working Group of the Whole was adopted by the Scientific and Technical Subcommittee at its thirty-first (1994) session (A/AC.105/571, para. 22), and the recommendations contained in the report were endorsed by the Committee on the Peaceful Uses of Outer Space at its thirty-seventh session and by the General Assembly in its resolution 49/34 of 9 December 1994.
3. In response to the request of the Working Group of the Whole, the Secretariat has prepared the present study. The purpose of the study is to provide a review on the applications of satellite-based radio broadcasting services, primarily for the benefit of countries that have not yet used that technology but are interested in its potential benefits. The study was prepared using a variety of national and international sources, which are listed in the selected bibliography (see annex). A summary of the study is provided below. The study, which is available in English only, is presented in the annex to the present note.

SUMMARY OF THE STUDY

4. Existing radio broadcasting systems have many deficiencies. Amplitude modulated (AM) radio suffers from bandwidth limitations, interference from other stations, especially at night, and electrical interference from power lines, machinery and household appliances. Frequency modulated (FM) radio was planned and designed in the 1950s to deliver high-quality sound to fixed receivers. It was not designed for portable or mobile use. The advent of cheap portable receivers and the marketing advantages resulting from providing FM radio in cars has changed listening habits and needs. Unfortunately, FM radio suffers from multi-path interference and other effects when used in portable and mobile environments.
5. Both AM and FM radio fail to offer uniform technical quality throughout their intended coverage areas. The present AM and FM broadcasting systems have used the frequency spectrum inefficiently and restrict the development of new services. Digital broadcasting will be widespread before the end of the century. It is believed that ultimately a global international standard will be developed and introduced. Such a standard will allow the use of common frequency bands and therefore enable the development of a universally

compatible and inexpensive receiver. Recent developments in satellite technology now make it feasible for portable and mobile radios to receive transmissions directly from satellites in the geostationary orbit.

6. For this reason, there has been much interest expressed about those systems among the various satellites projects designed to provide different types of services that are now under development that will provide country-wide broadcasting of radio and television programming. Although satellite sound broadcasting has been discussed for over 20 years, it is only recently that technological developments have rendered this concept practical. The possibility of using satellites to transmit television signals has prompted reflection on their use for sound broadcasting as well. Satellite sound broadcasting is a replacement technology for terrestrial radio broadcasting systems. The key differences in technology between terrestrial and satellite radio broadcasting systems relate to coverage, fidelity and convenience.

7. Satellite sound broadcasting involves the transmission of audio and auxiliary data transmissions directly from a satellite to low-cost receivers with semi-omnidirectional antennas. The audio programming is up-linked to the satellite from various locations, usually near the studios of a terrestrial radio station. Direct rebroadcasting of the audio programming via satellite greatly increases the coverage area of a radio station, while eliminating the need to use large amounts of kilowatts of power for broadcasting. Where the satellite line-of-sight is permanently obstructed, for example in tunnels, it can be complemented by a terrestrial transmitter operating on the same frequency. Such a hybrid satellite-terrestrial system can easily be implemented using digital techniques and is economical.

8. All current satellite sound broadcasting projects are planning for the audio fidelity associated with either FM radio or compact disc recordings. It is generally accepted that satellite sound broadcasting provides an economic means of covering large areas with a radio signal. Current digital satellite radio projects have per channel costs that compare favourably to those of major international shortwave broadcasters. Improved audio fidelity is planned for satellite sound broadcasting to encourage consumers to purchase the new satellite radios, in addition to providing more reliable signal reception across large geographical distances. However, there are currently over 2 billion radios in use (nearly half of them in the developing countries), more than the number of telephones and television sets combined, and only successful penetration of such a large potential customer base will ensure the economies of scale needed to reduce the costs of digital radios to the current level of analogue radios.

9. Digital audio broadcasting technology has sought to meet broader needs than analogue broadcasting. These include the capability of providing radio service to remote, rural and developing regions where the terrestrial infrastructure does not exist or cannot be economically or readily provided; the capability of providing high-quality reception to portable or car radios; spectrum efficiency to overcome the problems of spectrum congestion and the limited availability of services; and the capability of being power efficient, especially to meet the needs of the satellite transmission systems. Indeed, while countries such as the United States of America enjoy an average of 30 radio channels per million persons, most countries in the world have an average of only two channels per million persons. Developing countries are likely to see this technology as an economical means of delivering broadcasting services which have, to date, been expensive and slow to develop. In more developed countries, terrestrial digital sound broadcasting might also be an attractive alternative to existing AM and FM sound technologies.

10. The 1992 World Administrative Radio Conference (WARC) paved the way for satellite radio broadcasting. In comparative terms, the new radio broadcasting service received an amount of electromagnetic spectrum nearly twice as large as all previous radio broadcasting allocations combined. When considering the appropriate allocations to satellite sound broadcasting, it was taken into account that this service has a unique ability to help facilitate national development. As a broadcasting service, it is capable of providing a country's entire population with access to vital health, education and weather information.

11. Similarly, the first World Telecommunication Development Conference, held by the International Telecommunication Union at Buenos Aires, from 21 to 29 March 1994, declared that development strategies should encompass sound and television broadcasting via terrestrial and satellite systems as one of the key factors in promoting social and cultural development and that the broadcasting technologies being developed would provide opportunities, including those of distance learning, for a greater contribution to development.

12. Many large countries still have large rural tracts with little or no radio service other than unreliable high-frequency (HF) services. Due to poor road infrastructure, millions of persons in newly developed countries often have to commute for several hours and are sometimes delayed in heavy traffic during which time they tune in to radio. Burgeoning personal automobile markets in these countries will provide a high demand for satellite digital audio. Hence, the satellite sound broadcasting service represents the first stage of national telecommunications development: that of regularly providing a nationwide radio communication service with meaningful programming. A satellite sound broadcasting system should also include an auxiliary data capability to enable services such as nationwide paging via satellite. For many developing countries, satellite sound broadcasting represents the only practical way in which to establish the kind of nationwide paging services currently enjoyed in some developed countries.

13. Telecommunications in general, and satellite sound broadcasting projects in particular, are capital-intensive activities that require ongoing investment to expand and modernize the service. The majority of telecommunications capital spending is currently taking place in developed countries. For instance, of an estimated US\$125 billion spent on telecommunications in 1992, roughly 80 per cent was in high-income countries. Clearly, the developing countries will have to invest more resources if the telecommunication gap is to be reduced. The problem is not strictly a shortage of money – practically every telecommunications operator in the world is profitable – but rather one of national priorities and the relative importance afforded to telecommunications.

14. The international satellite industry has historically been highly regulated. Recent changes in the telecommunication sector have spilled over into the satellite industry. The result has been changes in national satellite policies, the policies of the International Telecommunications Satellite Organization (INTELSAT), as well as the introduction of private satellite systems. The resulting competition has produced growth and innovation in services, smaller and more flexible earth stations and lower prices. To implement a satellite network it is necessary not only to have the financial and technological capability to launch a satellite, but also to obtain an orbit position that would adequately serve the target area and to coordinate the frequency assignment to avoid interference with other satellite radio signals. The developing countries' concerns over accessibility are based on the natural limitations of the geostationary orbit and frequency spectrum.

15. There are many important international, regional and national satellite digital audio broadcasting (DAB) systems, services, projects and programmes currently being developed, including WorldSpace and INDOSTAR, to introduce services into the developing countries, the INTELSAT Digital Audio Distribution (DAD) system, as well as the systems being developed by the Satellite CD Radio, American Mobile Radio Corporation, Primosphere Limited Partnership, Digital Satellite Broadcasting Corporation and the European Space Agency (ESA). A relevant terrestrial project, the Eureka 147 programme, is also under development by a consortium of European companies. The above-mentioned projects are briefly described in the annex to the present note.

Annex

SATELLITE-BASED RADIO BROADCASTING

Study by the Secretariat*

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*The present study has not been edited. Mention of firm names and commercial products does not imply the endorsement of the United Nations.

INTRODUCTION

A. Satellite communications and broadcasting for development

1. Information is becoming an increasingly important global asset. Information is the primary driving force in the accelerated development of both industrialized and developing nations. It helps to create new markets and jobs and to improve national efficiency and productivity. Expansion of this process is highly dependant on the spread of information-related technologies. It is no longer possible for a nation or a region to embark on a development programme without the support of a modern telecommunications infrastructure. Yet, as in the past, some national governments remain reluctant to take the steps necessary to implement the technological infrastructure development needed to take advantage of modern communications technologies. In this sense, many outdated policies and attitudes remain an impediment to the technological development of countries.
2. Some governments of industrialized countries have committed themselves to changing the role that governments play in the information revolution. This has led to initial work on the establishment of national information infrastructures which will seek to combine computer networks, databases and consumer electronics into a single infrastructure capable of delivering to its users tremendous amounts of information. An integral part of these infrastructures will be the highly-trained personnel that will be needed to build, maintain, and operate the various sub-systems that will comprise the overall communications infrastructure. The ultimate goal of the planners of these national systems will be convergence of the national information infrastructures into one global infrastructure serving the entire international community.
3. Many developing countries find that, while basic services should remain in the governmental sector, rapid technological development compels them to provide value-added services through the private sector. This has led to a wave of deregulation of the postal, telephone and telegraph (PTT) organizations in many developing countries. Yet, without modern infrastructure, developing countries cannot attract the foreign investment or loan capital from international lending institutions that is often necessary for private sector industrial development. International telecommunications networks are largely a collective, cooperative and pragmatic process, even though there is fierce competition for the provision of services and equipment. The transfer of telecommunications technology involves contentious issues of standardization of equipment and protocols for interconnectivity, as well as problems of bandwidth allocation, and equitable access to information. All these issues have significant social and economic ramifications. Central to this process of technology transfer is the convergence of computer and telecommunications technologies.
4. Of all the new telecommunications technologies, satellites have the potential to make the greatest impact on the distribution of information. Satellite communication systems can make communications truly universal, even reaching the most inhospitable parts of the world. Satellites are and will continue to be an essential element of the growing and improving communications infrastructure. This is because satellites possess the following characteristics: ubiquity, mobility, distance insensitivity, and resiliency.
5. As a result of these unique features, satellites already play an essential role in global communications, providing video, data and audio services to locations that are not covered or cannot be reached by terrestrial communications. Even with the emergence of underwater fibre-optic cables, satellites still carry about 50 per cent of all international communications traffic. They are the input source to most terrestrial TV distribution networks.
6. Via satellites, rural and remote schools have access to up-to-date information, delivered by the best professionals in the field. In a rapidly changing world, where a well-educated workforce and lifelong education are essential to economic strength, the importance of accessible and affordable information and

communications tools are of paramount importance. New technologies, such as advanced simulation and training, tele-presence, and virtual reality, can facilitate education. These technologies will also create continually increasing demands on our telecommunications infrastructure.

7. In business, satellites have made it possible for corporations to cooperate efficiently almost everywhere on Earth. Information and communication technologies have become instrumental in virtually every business and are used for product development, manufacturing, marketing, sales and service. These new technologies have helped to improve productivity and increase innovation in almost every sector of the world economy.

8. Health care is another area where satellites will play a critical role in the future. New communications and information applications will allow: on-line patient records; remote diagnosis; and advanced medical analysis and simulation.

9. The satellite communications industry is beginning to aggressively pursue its role in the emerging national information infrastructures. Among the many projects currently under development that will utilize satellites to provide different services, there are several that will utilize satellites for direct, country-wide radio and television broadcasting. Notwithstanding the progress that has been made in recent years, the satellite communications industry must become more active in the development of standards and protocols that will govern the future architecture of the information infrastructure. A number of technical and regulatory issues still need to be resolved if the vision of an integrated information infrastructure is to be achieved.

B. Digital Broadcasting

10. Existing radio broadcasting systems have many deficiencies. AM radio suffers from bandwidth limitations, interference from other stations, especially at night, and electrical interference from power lines, machinery and household appliances. FM radio was planned and designed in the 1950s to deliver high-quality sound to fixed receivers. It was not designed for portable and mobile use. The advent of cheap portable receivers and the marketing advantages resulting from providing FM radio in cars has changed our listening habits and needs. Unfortunately, FM radio suffers from severe multi-path interference and other effects when used in portable and mobile environments.

11. In terms of coverage, both FM and AM radio fail to offer uniform technical quality throughout their intended coverage areas. The geographical limit of coverage is extremely poorly defined. This leads to audience dissatisfaction and poor spectrum efficiency. The present AM and FM broadcasting systems have used the frequency spectrum inefficiently and restrict the development of new services. There simply is not sufficient room for new stations in the larger markets. One of the primary objectives of the new broadcasting services is to encourage a wider range of these, particularly open narrow-casting services. For these systems to succeed, they will need to broadcast on the same bands as other broadcasters so that they can be received by normal radio receivers.

12. Digital broadcasting will be widespread before the end of the century. It is believed that ultimately a global international standard will be introduced that will allow the use of common frequency bands and therefore enable the development of a universally compatible and inexpensive receiver. Digital technology has already become the standard for electronic communication and there are several reasons why radio broadcasting is also likely to be digitized. The rapid replacement of the vinyl record market by compact discs shows that users want digital technology and sound quality. Similarly, Mini Discs and Digital Compact Cassettes are taking over the market of analogue cassettes. Many broadcasters are already using digital technology within their studios and for communications with other stations and for outside broadcasts.

13. Because digital broadcasting systems are not compatible with current broadcasting systems, a new receiver will have to be developed that is capable of receiving digital programming. Despite this hurdle, digital broadcasting systems offer the possibility to fundamentally change all broadcast media by offering multi-channel, multimedia, and other high-quality features that consumers are increasingly demanding. In this context, it will be important for manufacturers to develop and produce systems that will be able to provide the services consumers want at a cost they can afford.

14. The digitalization of broadcasting systems does not only involve the switch from an analogue system to a digital system, but also offers the possibility of radically changing programme production techniques and integration of information reception and processing. Digital technology has already been introduced into the broadcasting field and is now used in studio equipment, TV receivers, video tape recorders and other equipment. Digital technology is also used for broadcasting the PCM sound of the digital sub-carrier/NTSC system, teletext, and FM multiplexing. The signals of these broadcast systems are multiplexed with the analogue signal of the main services, but systems that use dedicated digital channels are now being developed.

15. Recently, there has been significant progress in the development of highly-efficient audio and video encoding technology for use in communications and electronic products. Such technology, particularly when utilized for the digital transmission of television signals, increases the efficiency of frequency utilization. This has occurred in tandem with society's growing need for new information technologies and has, in turn, prompted the development of new types of data services and data broadcasting systems. One of these new systems, Integrated Services Digital Broadcasting (ISDB), has been developed as a broadcasting system to digitally integrate information such as television, sound and data in order to flexibly provide various kinds of services. ISDB will have several advantages if it is fully developed into a new broadcasting infrastructure, including efficient frequency utilization, its ability to accommodate many different service broadcasters and to supply new services suited to user demand.

16. ISDB will benefit from the overall advantages of digitalized broadcast production, signal transmission and reception. Digital production equipment for news-gathering and digital studio facilities, connected by digital lines, will result in a more efficient production environment. Digital signal transmission technology will also allow broadcasters to offer more channels, providing a diverse array of services. Information provided by these services will be sent to homes without quality deterioration through a single integrated receiver. By integrating circuits in large-scale integrated circuits, small, low-cost receivers can easily be produced.

17. There are many possible ways in which ISDB signals can be transmitted, including via 22 GHz, 12 GHz, and 2.5 GHz satellite channels, terrestrial channels and optical fibre cables. Among these, the satellite broadcasting channels in the 12 GHz-band have the most potential. It must be noted that when a broadcasting signal is transmitted by digital modulation techniques and using only one satellite broadcasting channel, the interference protection ratio used in WARC planning, which dictates that no interference can be detected in the same channel, must be adhered to.

18. Digital compression techniques have improved sound quality so much that it is now possible for radio signals to be broadcast from a living room, a sports stadium or a restaurant with excellent sound quality. The sound heard by radio listeners often travels over telephone lines. This has been made possible by two parallel developments. First, to encourage private industry to use Integrated Digital Services Networks (IDSN) systems to carry digital signals between computers, video conference cameras and high-speed fax machines, some telecommunication operators now charge the same rates for digital calls and analogue calls. Second, the electronic industry has built coders that convert studio quality analogue sounds into digital code and compress it into a data stream which can be sent through IDSN networks with no discernible loss of quality.

Conventional twisted-pair telephone lines carry an analogue audio signal with a bandwidth of less than 4 KHz, giving a "boxy" sound when replayed on the radio. An ISDN line, on the other hand, carries two separate digital data streams, each running at 64 Kbit/s, which therefore results in better sound quality.

I. Technical, economic and regulatory aspects of digital broadcasting by satellite

19. Although audio broadcasting via satellite has been discussed for over 20 years, it is only recently that the technology has matured to the point where the concept is practical. New technological developments in audio broadcasting are aimed at improving the efficiency of conventional services through a more rational and cost-effective use of existing resources (frequency bands, equipment and networks), and the introduction of new services.

20. Consideration has been given to the possibility of using a whole television channel to transmit a multiplex of stereo programmes or to use the sound/data time multiplex element of a Multiplexed Analogue Component (MAC) television channel to transmit independent sound programmes. Such systems would require fixed reception equipment and would always be linked to television systems. Accordingly, following studies carried out by the European Broadcasting Union (EBU), the Consultative Committee of International Radio Communications (CCIR) has contemplated the possibility of introducing satellite sound broadcasting in the 0.5-3 GHz frequency band using stationary, portable or mobile receivers. (This possibility had also been considered by the 1979 WARC, as well as the ORB-85 and ORB-88 conferences which were special sessions of the WARC on the use of the geostationary satellite orbit and the space services utilizing it.)

21. Satellite audio broadcasting systems could economically cover vast areas, thereby providing total coverage of a whole country, with a constant reception quality and a vast choice of programmes. The sound quality would be comparable to that obtained by other digital sound reproduction equipment such as compact disc players.

22. Consideration is also being given to the development of a low-cost FM system capable of using existing FM receivers. These are particularly suitable for use in countries at low latitudes where there is virtually no signal attenuation due to signal blocking. Simple digital systems could also be economical, in particular for monophonic broadcasts. More advance receivers may be needed for use in large towns, especially those at higher altitudes, where reflection and absorption occur more frequently.

23. Satellite audio broadcasting would replace existing terrestrial radio broadcasting systems, including short wave radio (high frequency band, 3-30 MHz), long wave radio (AM band, 0.5-1.5 MHz), and medium wave radio (FM band, 88-108 MHz). The key differences among these radio broadcasting systems relate to coverage, fidelity, and convenience. Satellite audio broadcasting is functionally similar to short wave and AM radio in that it is designed to cover very large geographical areas, such as whole countries or continents. However, a satellite audio broadcasting system would accomplish its coverage with direct, line-of-sight connections between user radios and the satellite, whereas a short wave radio broadcasting system achieves coverage via ground-wave and sky-wave propagations. A satellite transmitter requires only about 50 W of solar panel power to achieve the same radio coverage as a standard 500 KW ground-based short wave transmitter.

24. Satellite sound broadcasting differs from shortwave and AM systems in that it is being developed to serve as a high-quality audio medium. Although satellite sound broadcasting need not be digitally modulated, all current projects anticipate digital modulation to enable the sophisticated coding schemes needed to permit low-gain, mobile receiving antennas. Although digital modulation does not by itself provide an improvement in audio fidelity compared to that available over short wave or AM radio systems, all current satellite sound broadcasting projects are being designed to provide the level of audio fidelity associated with FM radio and

compact disc recordings. This high level of audio fidelity is being planned for satellite sound broadcasting systems as a way to encourage consumers to purchase the new satellite radios.

25. Satellites have been used for many years to transmit radio programming across large areas for reception by large terrestrial antennas and subsequent re-transmission by ground transmitters. But, satellite radio broadcasting to audiences in mobile vehicles was not possible because the satellite power received on the ground was never strong enough to be received by a portable or mobile radio equipped with an omnidirectional antenna.

26. Satellite sound broadcasting represents the culmination of 30 years' effort to reduce the size of satellite receiving terminals. Spread-spectrum satellite data networks developed in the 1980s paved the way for development of mobile satellite navigation and portable satellite sound broadcasting systems in the 1990s. It is now economically practical to provide much of the signal gain (about 20 db) generally offered by satellite ground antennas.

27. The ratio of satellite power to downlink frequency has increased due to higher-power satellite transmitters and new frequency allocations in the lower microwave region between 1.4 and 3.6 GHz. This reduces the amount of antenna gain needed to receive a satellite radio signal from what was required with earlier point-to-multipoint satellite radio redistribution systems. This is due to the inverse-square relationship between wavelength and the necessary transmission power for a given received power flux density on the surface of the Earth. Finally, the need for directive satellite ground antennas has been reduced by sophisticated coding techniques. This minimizes the necessary data rate that must be decoded by the satellite radio receiver, thus improving the efficiency of the system.

28. Satellite sound broadcasting techniques have also been developed to deal with the variable fading characteristics of a mobile channel. In traditional satellite communications systems, variable fading arises only from rain, and the terrestrial receiving stations are sized appropriately to compensate for rain losses with built-in margin (greater gain). But with satellite sound broadcasting systems, the quality of free-space channel between a radio receiver and the satellite can change almost constantly and unpredictably, as in the case, for example, of a satellite radio-equipped car passing by buildings, trees and other line-of-sight obstructions.

29. There are three satellite sound broadcasting techniques to mitigate the variable fading characteristics of a mobile channel: space diversity, time diversity, and frequency diversity. The common element in each of these techniques is a reliance on the fact that mobile-link fades occur differentially in space, time and frequency. For example, by spreading a source signal among several frequencies, a signal loss at any particular frequency need not be perceptible to the listener because the radio still receives the major portion of the signal at the other frequencies. Similarly, a source signal can be divided randomly in many microsecond-level time blocks. Fades that affect some time blocks need not be perceptible to the listener so long as most of the time blocks are not affected. The most effective satellite sound broadcasting anti-fading techniques combine frequency and time diversity. Space diversity requires multiple antennas, a feature that to date has limited its attractiveness among system developers.

30. Current audio source coding technology allows the following correlations to be made between satellite sound broadcasting rates and audio fidelity: 256 Kbit/s: stereo compact disc quality; 64 Kbit/s: monophonic FM-radio quality; and 32 Kbit/s: monophonic AM-radio quality. Generally, satellite sound broadcasting projects targeted at Europe, North America, and Japan are being designed for compact disc quality. Satellite sound broadcasting systems for developing countries are being designed to operate at 64 kbit/s to enable a qualitative fidelity upgrade from short wave radio, while reducing satellite power requirements (and hence cost) by a factor of four compared to the 256 kbit/s compact disc-oriented systems.

31. Some specialists argue that if these types of systems are to be introduced in developing countries, there must be good prospects for them to remain in service for many years. The systems that are currently only in the research and development phase, such as direct digital audio broadcasting systems, should be avoided by developing countries. These countries should instead rely on established satellite providers such as INTELSAT, INMARSAT and EUTELSAT to provide the space segment for radio broadcast systems. With regard to the terrestrial element of radio sound delivery systems, serious consideration should be given to improving programming delivery, both in extent and content, to fixed installations and local rebroadcasting capabilities. This would ensure that the existing receivers could be used to provide improved reception quality. Should direct satellite reception become available, it could be introduced progressively once it became clear that the system would continue operation and that reasonably priced reception equipment would be available.

32. Opponents of DAB systems consider it unlikely that any significant proportion of the new digital receivers will be manufactured in developing countries in the first few years after such systems become operational. On the other hand, because the technology required for manufacture of receiving equipment for existing satellite broadcasting systems is relatively mature, it is possible that developing countries will become involved in the manufacture of these items. Developing countries would also be able to insert locally-produced programming through local receiving and distribution stations.

33. Satellite sound broadcasting radio receivers are being designed to be much more convenient to use than the short wave systems they will replace. Tuning of the new satellite digital radios will be accomplished by arbitrary channel numbers rather than by kilohertz or megahertz designations. This is because the digital radio broadcasting systems will be able to reassign radio frequencies to different channel numbers, and command all radios to display the currently appropriate channel number for each frequency. Each broadcast will also include digital information regarding the programme name and format. The new digital radios will be able to display these names, thereby enabling listeners to tune into the desired programme using this textual information. Finally, the new radios will be individually addressable via a unique, built-in identification code. This feature will enable each digital radio to also serve as an alphanumeric paging terminal and as a receiver for facsimile messages. The digital paging and facsimile message information would be interspersed with the digital audio information. This "addressability" feature will allow a broadcaster to create software-defined radio sub-audiences, based on national markets or monthly subscription fees. For national markets, certain broadcasts could be restricted to those identification numbers reserved by a particular country for the radios its citizens have imported or its companies have manufactured.

34. Radio networking is now conducted exclusively through geosynchronous satellites utilizing microwave transmit-receive technology to uplink frequencies in the 6 GHz frequency range, and to downlink in the 4 GHz range (C-band). Existing Fixed Satellite Services (FSS) satellites repeat the signal on assigned transponder frequencies, beaming a broad pattern of signals that can cover an entire continent. The signal may be received in any location by an affiliated radio station utilizing low-noise receiving amplifiers centred in the focus of the microwave receiving antennas tracking the satellite.

35. There are three concepts governing the planned interoperability between satellite and terrestrial digital audio radio systems. First, the satellite sound broadcasting system could be used to simply uplink, rebroadcast, and down-convert terrestrially broadcast digital signals. This is similar to the way home satellite dishes currently receive "superstation" television programming via up-links and rebroadcast local television signals. A second possibility is that the terrestrial digital radio transmitters could simply rebroadcast the satellite sound broadcasting signals. The purpose of this method would be to permit continuous, reliable reception of digital audio signals even when buildings or tunnels block the line-of-sight to the satellite. Experiments conducted by the EBU in 1990-1991 proved that digital signal processing techniques permit co-channel transmission of satellite and terrestrial digital audio signals with the radio receivers constructing a

coherent signal based on the strength of the received signal. A third concept is to have independently operated systems that could be received on a single radio receiver. For example, a terrestrial digital radio service might operate in frequencies adjacent to a satellite digital radio service. A single radio receiver would tune across both bands, picking up local (terrestrial) broadcasts on one band and national (satellite) broadcasts on the other.

36. The potential benefits of satellite-terrestrial radio interoperability have reinforced the need for standardization. Digital radio standards must be agreed upon at a detailed technical level to ensure that a radio can operate with both a satellite system and dozens of local digital broadcasting stations. Much of the work towards digital standardization is being carried out in the ITU. However, it now appears that different standards will be adopted for Europe, the United States and other countries and regions. Countries that are located on or near the equator have relatively high satellite elevation angles which will minimize the need for terrestrial repeaters. Hence, a simple down-converting and demodulation of satellite signals for listening over existing radio sets may prove to be the most sensible approach.

37. It is generally accepted that satellite sound broadcasting provides an economic means of covering a wide area with a radio signal. Current digital satellite radio projects have channel costs that compare favourably to those of major international short wave broadcasters. However, the latter group accesses millions of existing shortwave radios, while a satellite radio broadcaster will initially face a dearth of radios at the inception of service. A digital radio must include, at a minimum, an antenna, down-converter, demodulator, and audio decoder. An audio processing board, speaker, and housing will generally also be needed. The prices of currently available satellite radios, though comparable to those of other high-fidelity audio equipment, are still significantly higher than those for standard analogue radios. However, because there are over 2 billion standard analogue radios in use, more than the number of telephones and television sets combined, it is hoped that manufacturers will ultimately be able to ensure the economies of scale needed to reduce the costs of digital radios to the level of analogue radios.

38. Consumers need to know that there are attractive radio programmes before they will purchase a digital radio. However, radio broadcasters and programmers will be reluctant to make the switch to satellite sound broadcasting channels in the absence of a large audience. This dilemma might be addressed in three ways: a) Satellite digital radios could be designed into multi-band radios for gradual market growth; b) Satellite digital radios could be sold to developmental aid organizations for free distribution in poorer countries; and c) Programmers' fees could be calibrated to the level of radio set distribution. Since there is little operating cash flow from which satellite sound broadcasting systems can be economically self-sufficient in their early years, such systems generally are proposed as experimental programmes until they achieve a commercial threshold of radio receiver set distribution.

39. The primary purpose of the WARC-92 was to reach global agreement on which radio frequency bands should be reserved for certain new technologies. In addition, this Conference sought to develop internationally agreed-upon rules pursuant to which geostationary and non-geostationary satellites could share overlapping swaths of radio frequencies, and to effect a slight expansion of frequencies allocated for short wave broadcasting in the HF band and for position-reporting in the very-high frequency (VHF) band.

40. In many ways, WARC-92 paved the way for satellite radio broadcasting and for personal mobile satellite communications. Many new space technologies had emerged since 1979 when the last frequency allocating WARC was held. One of the most important of these is Broadcasting Satellite Service Sound (BSS-Sound) which transmits digital audio broadcasts directly from satellites to portable radio receivers. At WARC-92, proponents of BSS-Sound sought approval for use of frequencies in the 1-2 GHz (L-band) and 2-3 GHz (S-band) ranges.

41. The concept of digital audio broadcasting has been under consideration for many years. Finding suitable technical solutions has been an issue within the CCIR for over twenty years. Apart from the well-known needs of all radio broadcasting, digital audio broadcasting has sought to meet wider objectives, including: provision of radio service to remote, rural and developing regions; provision of high-quality reception to portable or car radios; achievement of spectrum efficiency to overcome the problems of spectrum congestion and the limited availability of services; and power efficiency, particularly to meet the needs of satellite transmission systems.

42. "Direct-to-listener" reception from a satellite is a concept that incorporates the idea of reception by mobile, outdoor portable, and indoor portable receivers. What distinguishes radio broadcasting from the direct broadcasting of television is that the receiver/antenna system must work even if there is no direct-line-of-sight to the satellite from the receiver's antenna. Most planned systems using this concept are being designed for rural, suburban and urban use. Some systems under development are concentrating on mobile reception while many consider indoor reception to "table top" radios to be equally important. This collection of requirements necessitated frequency allocations somewhere between 0.5 and 3 GHz for satellite delivery. Lower frequencies would require spacecraft down-link antennas to be very large and higher frequencies would require excessive power levels per broadcast channel.

43. During the 1980s there was not much interest in the introduction of digital audio broadcasting services, either via terrestrial or satellite delivery. Two industry groups, one American and one European, largely within the confines of CCIR activities, studied the possibility of developing feasible broadcasting services. These studies were primarily concerned with satellite delivery. These studies and discussions held at several WARC's, indicated that some developing countries were indeed interested in the introduction of direct satellite radio broadcasts. The main interest from the industrial countries, however, was concentrated on the value of providing "compact disc"-quality audio programming for cars and other vehicles.

44. Between 1988 and 1992, several organizations noted the need, on a worldwide basis, for audio channels with less than CD-quality reception. This prompted more developing countries to become interested in direct radio broadcasting via satellite. Therefore, when WARC-92 was convened, just about every country in attendance was in favour of allocating some spectrum for BSS-Sound somewhere between 0.5 and 3 GHz.

45. Member States of ITU gave WARC-92 the task of finding available frequency spectrum for satellite and complementary terrestrial audio broadcasting. However, the Conference did not specify a delivery system or technology for digital audio broadcasting. It simply allocated spectrum for these services. It also did not deal with spectrum for systems that would only work terrestrially. This was despite the fact that prior to WARC-92, many studies had been conducted on the spectrum requirements for the various broadcasting systems then under consideration or under development, including the system being developed by the Eureka 147 consortium, as well as systems being proposed for use in the United States, Africa, and Asia.

46. When WARC-92 began, it was clear that there were widely divergent views on spectrum allocation for satellite audio broadcasting systems, particularly among the developed countries. For example, the European delegation was opposed to the use of the L-band even though it is much less expensive to utilize than the high frequency S-band frequencies that were advocated by the United States. The final decision of the Conference supported the use of the L-band even though the spectrum will not be fully available in some regions of the world until 2007. It was determined that sufficient spectrum for viable broadcast systems could be provided before then in many countries. The United States opposed this decision and remains committed to using the 2.3 GHz band for satellite broadcasting. The primary reason for this opposition is that the radio broadcasting industry in the United States is only interested in digital audio for improving the audio quality of local terrestrial broadcasting that is conducted under existing licensing arrangements and the overall

structure of roughly 11,000 radio stations. These broadcasters are nearly unanimous in their aversion to the introduction of satellite delivery of digital audio broadcasting, with its wide area possibilities.

47. The final compromise reached at WARC-92 was to allocate three frequency bands. Each nation accepted one or more of these bands, sometimes with conditions limiting their use until 2007. There are some spectrum management nuances related to the introduction of the service on a co-primary basis and the need to coordinate with neighbouring nations, but the following frequency spectra were allocated:

- 40 MHz in L-band (1452 - 1492 MHz)
- 50 MHz in S-band (2310 - 2360 MHz)
- 120 MHz in S-band (2335 - 2655 MHz)

Roughly half of the world's population lives in nations that chose the L-band allocation and the other half preferred one of the S-band allocations.

48. In comparative terms, the new and planned radio broadcasting services received an amount of spectrum nearly twice as large as all previous radio broadcasting allocations combined. Short wave, AM, and FM radio have about 22 MHz total bandwidth, whereas the new BSS Sound service was awarded 40 MHz total bandwidth worldwide, from 1452-1492 MHz; 50 MHz additional bandwidth, from 2310-2360 MHz, in the United States and India; and 20 MHz additional bandwidth in a number of other countries. This band will be used, on the basis of future planning, for satellite digital audio broadcasting only, in conjunction with terrestrial digital audio broadcasting.

49. In the meantime, provision has been made for early system development for national or regional BSS in the upper 25 MHz of each of the three bands and terrestrial use before a Planning Conference around 1998, and in advance of the allocated spectrum being available for primary use by all countries in the Year 2007. The implementation of this service will probably be delayed in some countries or regions because of the difficulties in transferring the existing radio services to other frequency ranges. Spurred on by activities leading up to WARC-92, which dealt primarily with satellite delivery, there has been significant interest in the use of modern digital techniques for purely terrestrial radio broadcasting in the existing radio broadcasting bands (both FM and AM).

50. Several systems are currently being developed to broadcast radio programming directly from satellites in the geostationary orbit to inexpensive home, vehicle-mounted, and portable radio receivers. These projects share a common emphasis on the use of digital signal modulation, audio source information compression into a reduced bandwidth, and transmission in select portions of the electromagnetic spectrum at frequencies from 1452-1492 MHz and from 2310-2360 MHz. Service on some of these systems is scheduled to begin in certain regions in 1994 and global service is expected to be achieved around 2000.

II. SATELLITE DIGITAL AUDIO BROADCASTING SYSTEMS UNDER DEVELOPMENT

A. Worldspace

51. Worldspace is a for-profit corporation founded in 1990 in the United States to develop and provide a worldwide satellite-based digital audio service. Worldspace itself is not a programmer; the company will not originate its own programming, but the company will make satellite-based digital audio broadcasting available to broadcasters worldwide. In short, Worldspace will develop satellite systems and sell the channels on those

satellite systems to broadcasters who wish to provide wide-coverage, high quality broadcast services to their listeners.

52. Worldspace will implement these systems through regional subsidiaries called AfriSpace (covering the African-Middle East region), AmeriSpace and CaribSpace (covering Central, South America and the Caribbean) and AsiaSpace (covering the South-East Asia/ and Pacific rim region). Each regional subsidiary is wholly owned by the Worldspace holding company. The holding company and its subsidiaries are composed of an international consortium of recognized experts in the satellite and electronics industries.

53. WorldSpace has used a market-driven approach to developing its various satellite digital audio broadcasting systems. The company conducted a feasibility study to determine problems with existing radio delivery systems in its targeted regions and then develop solutions to those problems. The main conclusions of this study were:

- a) Terrestrially-based solutions for mass-media have been particularly problematic in many of the developing countries due to terrain conditions, large land areas and low-population densities. These constraints were noted in many areas of Africa, Asia and Latin America. These factors indicated that in order to have the desired impact on these regions, satellite systems would be required for digital audio broadcasting;
- b) Existing radio delivery systems do not provide these regions with good quality sound. An improvement to the equivalent of FM-quality would represent a significant improvement from what is currently available. Delivery of FM-quality service would be sufficient for a great majority of the markets in these regions and dynamic multiplexing technology could provide higher fidelity sound where market conditions warrant it;
- c) There is a need for a wider choice of programming formats. Because of the costs involved in purchasing and operating even a single transmitter, most developing countries do not have the wide array of format choices that have become the norm in radio markets in the developed countries. It was noted that listeners would appreciate having a simultaneous choice of ten or more different formats from which they could choose;
- d) A majority of radio listening in the developing countries occurs on stationary receivers, compared to the developed countries where mobile listening is more common. It would therefore not be necessary, for most regions of the world, to spend the additional amount of money to combat the multi-path propagation difficulties that occur in mobile reception environments; and
- e) Cost would be the most sensitive element of the planned service in all regions. Radio broadcasting is a cost-sensitive industry characterized by inelastic demand. A related element of the cost equation is that there is a need to gradually increase the number of available channels so as not to immediately saturate the market.

54. WorldSpace is an experiment in region-specific solutions to region-specific needs. This is why it was decided to implement the service in regional blocks that covered Africa and the Middle East, Asia and the Pacific rim, the Caribbean and the Central America and the South America region. As such, WorldSpace was organized into four subsidiaries to implement region-specific systems with a view to ensuring regional participation and representation.

55. One of the key elements in this process of regionalization will be the development of a mixture of programming that has a larger content specifically developed for the region plus other programming reflecting the needs, the cultures, and the world view of nations outside that region.

56. It is expected that there will be three distinctive types of broadcast services that would utilize the Worldspace system. The first group would consist of regional broadcasters such as the Voice of Dubai, Voice of Brazil, Radio Jamaica, etc. The second group is expected to consist of international broadcasters such as the BBC, VOA, Radio Australia, etc., and the third group would consist of specialized broadcasters that would utilize the system because of its capabilities to reach broad audiences. Examples of such broadcasters include the World Health Organization, which would be able to broadcast health and hygiene information to the broad regions; educational institutions which could transmit university or secondary school-level educational programming; and international organizations such as the United Nations Education, Scientific and Cultural Organization (UNESCO) and the United Nations Children's Fund (UNICEF), which could transmit programming consistent with their respective mandates.

57. AfriSpace, one of the regional subsidiaries of WorldSpace, was created with the express purpose of providing a market-based solution to the problem of radio broadcasting on the African continent, particularly in the Sub-Saharan region.

58. In 1993 AfriSpace petitioned the United States Federal Communications Commission (FCC) for permission to construct, launch and operate what would be the world's first satellite-based, direct-to-listener radio broadcasting service covering the African and Middle Eastern region. The Petition before the FCC noted that AfriSpace was organized to sell or lease the channels on the satellite to broadcasters who wish to reach their audiences with better audio fidelity sound and to provide a wider coverage service than is presently available using terrestrial radio broadcasting techniques.

59. AfriSpace will itself not be a broadcaster but only a satellite operator acting on behalf of the broadcasters providing services to the region. The first satellite is scheduled to be launched in 1997 and placed in orbit at 12° W longitude, just off the coast of Senegal and Ivory Coast. The satellite will have a digitally modulated system with nine CD-quality channels (with about 256 kbit/s per channel data rate) which can be dynamically multiplexed into 36 channels, each with a data rate of 64 kbit/s.

60. The satellite system will cover Africa and the Middle East with three beams, each of which will cover approximately 8 million square kilometres. Each beam of the first satellite will have 12 channels. Thus, each channel will be able to reach a large radio audience. In the context of the African and Middle Eastern region, this would mean that each channel would cover over 200 million people spread across approximately 20 countries. This coverage capability would, in turn, facilitate broadcasts of health advisories and other educational and informational programmes to vast numbers of people.

61. On the basis of AfriSpace's petition to the FCC, and the overwhelmingly positive comments that came in from interested public and private institutions, the FCC initiated a process that culminated in a license for the company to construct, launch and operate its proposed satellite system. The 1992 WARC also made a worldwide L-band frequency allocation for the service.

62. AfriSpace has adapted existing technologies and developed new ones to enable low-cost, solar-powered digital radios known as StarMan FTM to receive audio signals directly from its satellites. The StarManTM radios will be equipped with digital signal processing chips and will be able to receive the signals transmitted by the satellite. This will thus provide a high audio fidelity service with signal quality ranging from the equivalent of FM radio to that of compact discs. In addition, they will be compatible with solar power systems and be able to provide a wide range of useful applications to both rural and urban areas such as tele-

medicine and tele-education. The radios will also have crystal displays to show paging messages and a standard interface that would allow interconnection with computers and printers for teletext information transfers.

63. The satellite itself is expected to deliver anywhere from 50 to 70 channels which will be divided equally among three beams. AfriSpace plans to lease or sell these channels to broadcasters who are currently unable to reach their entire potential radio audiences or that do so with very poor audio fidelity.

B. Systems under development in the United States of America

64. Following the decision on BSS-Sound reached at WARC-92, the United States FCC issued a Notice of Proposed Rule Making to allocate frequency spectrum domestically at 2310-2360 MHz for satellite and complementary terrestrial digital audio radio services (DARS), and at the same time invited applicants for licenses to provide these services. For this purpose, the FCC also accepted previously tendered applications. This process resulted in four DARS applications before the FCC. The proposed systems range from "hitch-hiker" transponders added to direct broadcast satellites already under construction, to a Martin Marietta Astro Space Series 7000-class satellite with a 20-m deployable antenna. Nominal channel bit rates of the proposed systems range from 55 kbit/s for monophonic FM to 384 kbit/s for CD audio. The majority of systems proposed envision CD-quality audio at 128 kbit/s using perceptual domain compression techniques. System capacities ranged from 25-512 channels and all of the proposed systems would provide coverage to the continental United States. Two would also cover Alaska, Hawaii and Puerto Rico.

65. One of the more contentious issues is the provision of CD-quality programming services to moving vehicles. All of the applicants agreed that mobile services are the most important DARS market. However, they disagree vigorously on whether a particular system could provide adequate link margin to provide these services. Similar questions have been raised about receiving DARS signals inside buildings.

Satellite CD Radio Inc.

66. The first system, proposed by Satellite CD Radio Inc. (SCDR), will be based on two, three-axes, stabilized geostationary satellites located at 80° W and 110° W longitude. SCDR's system will use the 2,200 kg Loral FS-1300 spacecraft with 3,300 watts of power. The SCDR system will serve the continental United States with 30 CD-quality channels at a data rate 128 kbit/s utilizing 20 MHz of spectrum, 10 MHz on each satellite. The SCDR system will simultaneously broadcast the same time division multiplex signal from both satellites. The system will lease transponders to programmers and therefore will not provide services directly to end users.

American Mobile Radio Corp.

67. The system proposed by the American Mobile Radio Corporation (AMRC) will be based on two 2,900 kg Hughes 601 class satellites, each with 3600 watts of power that will be placed into orbit at 93° W 101° W. One satellite will provide services to the continental United States and the other will provide services to the continental United States and Alaska, Hawaii, Puerto Rico and the Virgin Islands. AMRC has requested 5 MHz of spectrum for its satellite that will serve only the continental United States and 10 MHz for the satellite that will serve the off-shore areas. AMRC plans to operate as a private carrier and offer four types of channels to distributors and individualized programmers:

- CD-quality channels at 220 kbit/s
- FM stereo channels at 110 kbit/s
- FM monaural channel at 55 kbit/s
- data channel at 9.6 kbit/s

68. AMRC's nominal configuration is 10 CD-quality channels, 5 FM stereo channels, 5 FM monaural channels, and a single data channel. AMRC also intends to offer free, advertiser-supported services. AMRC's system is designed to transmit to vehicles via low-profile antennas. Higher gain antennas would be used in fixed applications such as on rooftops.

Primosphere Limited Partnership, Inc.

69. Primosphere Limited Partnership, Inc., has proposed a system consisting of two 2,450 kg satellites, each with 4,725 watts of power, to be located at 80° W and 110° W to provide single-beam coverage of the continental United States. The system will utilize the entire 50 MHz in 2310-2360 MHz band on both satellites with opposite circular polarization. The company proposes to provide a total 46 CD-quality channels at 384 kbit/s and 12 FM monophonic channels at 64 kbit/s, with 50 per cent of the channels to be broadcast from each satellite. Primosphere is the only applicant to request that it be regulated as a broadcaster, and the only applicant to propose only advertiser-supported services. (The other applicants propose to be regulated as private operators.) The system will transmit to flat omnidirectional vehicle antennas, and higher gain antennas will be used for fixed applications.

Digital Satellite Broadcasting Corp

70. The system proposed by the Digital Satellite Broadcasting Corporation (DSBC) will use one Martin Marietta Astro Space 7000-class, 3,500 kg satellite with 5,200 watts of electrical power. The satellite will be located at 101° W to provide service to the continental United States, Alaska, Hawaii and Puerto Rico. The distinguishing feature of the DSBC satellite is its 20 m deployable antenna which will form 31 regional spot beams to provide service to off-shore areas and to provide additional services to major population centres, in addition to the single beam serving the continental United States. Each spot beam will be approximately 350 km in diameter. DSBC's application included two system designs: its preferred design will utilize code division multiple access (CDMA) technology and the second, less efficient design would use time-division multiple access (TDMA) technology and would be compatible with all of the other applicants in case TDMA is authorized by regulatory authorities.

71. DSBC intends to utilize the 2310-2335 MHz band, the lower 25 MHz of the band that the FCC has proposed to allocate to these type of services, in order to provide 16 CD-quality channels at 128 kbit/s to the continental United States and an additional 16 CD-quality channels in each spot beam. The proposed DSBC system would provide truly mobile services using omni-azimuthal low-gain vehicle antennas. The choice of CDMA signalling technology for the system would mean that the digital signal processing and audio modules of its DARS receivers can also be used for other CDMA-based services such as terrestrial cellular telephone and mobile facsimile, as well as telephone and data services to be provided by various low earth orbit satellite systems.

C. Eureka 147

72. A European consortium, headed by France and Germany with support from the EBU and many European governments, has moved the process from the design phase to the hardware development phase. In 1988, this consortium, named Eureka 147, demonstrated CD-quality audio transmitted from a terrestrial transmitter into a moving vehicle. French, German, British and Canadian organizations have continued demonstrations, experiments, and pilot broadcasting operations with this system.

73. The Eureka 147 system is being tested primarily for use at VHF just above 200 MHz. The European plan would be to eventually cease broadcasting in the existing FM broadcasting band of 88.5-108 MHz, but in the interim to use the higher VHF frequencies. This may be a lengthy process. The Eureka 147 system

would require a full 1.5 MHz spectral block within which six CD-quality programmes could be broadcast via hundreds of sub-carriers. Each programme would have its sub-carriers spread across the entire 1.5 MHz. spectrum. The sub-carriers of the six programmes would utilize interleaved frequencies, which are signals transmitted over frequencies from two or more sources in time division sequence over a single path. It would not be possible to retain the current structure of local broadcasting, with individual transmitter towers and different coverage patterns, if this system is adopted.

74. All digital audio broadcasting systems have two basic components: the coding system used to compress the audio signals and the technology used to actually transmit the signal. The coding system to be used in the Eureka 147 system is known as MUSICAM. Its design takes advantage of the psycho-acoustic properties of the human ear to significantly reduce the data rate needed for high-quality audio. The primary mechanism used by MUSICAM is known as masking. This relies on the effect that a high level sound on one frequency prevents a low level sound on a nearby frequency from being heard. Hence there is no need to transmit the low level sound and it can be eliminated from the overall signal.

75. Most broadcast quality audio coders produce excellent results for almost all audio output. The challenge is to find out when they do not perform at optimum levels. Extensive listening tests have been done utilizing the MUSICAM technology as well as on a range of other compressed audio coders. These tests have indicated that MUSICAM is virtually indistinguishable from original CD material when operating at a data rate of 256 kbit/s (i.e. 2×128 kbit/s). It can, however, produce roughly the same performance at a data rate of 192 kbit/s. It is therefore expected that the initial broadcast standard for the Eureka system will use MUSICAM operating at 192 kbit/s. This is a compression ratio from the original CD material of about 7:1. MUSICAM has also been chosen as the standard for the audio channels on the proposed Moving Pictures Experts Group (MPEG), which is a motion video compression standard to provide both interframe and intraframe encoding for compressed digital TV. It has also been proposed for some of the in-band digital audio broadcasting systems in the United States.

76. The transmission system for the Eureka 147 system is a digital technology known as Coded Orthogonal Frequency Division Multiplexing (COFDM) which groups together several audio channels on one transmitter. It combats the selective multi-path fading by artificially reducing the symbol rate of the elementary carrier transmitted and allowing for symbol guard time. The COFDM system has been designed to broadcast several audio channels as an integrated digital signal from one transmitter. Recent research indicates that the optimum arrangements might be six stereo channels of 192 kbit/s each feeding into a single transmission channel of 1.5 MHz bandwidth. (The transmitted data rate would be over 2 Mbit/s after error correction bits are included.)

77. Such a system need not simply transmit six high quality stereo channels. It could be used for nine medium quality channels (about FM grade), or twelve AM stereo grade channels or more than 30 voice-grade channels. Any mixture of the above is technically possible, including channel splitting at certain times of the day. The Eureka digital audio broadcasting COFDM system will also support single frequency networks. In its simplest form this would see translators on the same frequency as the parent station with overlapping coverage areas. The Eureka system would handle such an arrangement by using the two signals to reinforce reception rather than having the two signals interfere with each other.

78. Terrestrial selective multi-path effect is virtually eliminated in the Eureka system and the limit of coverage is generally well-defined. Performance measurements made at the L-band have shown that coverage is very even throughout a transmitter's service area. Any areas of poor reception such as behind obstacles or in valleys can be rectified with low-cost on-channel translators. The capability of having translators on the same frequency as the parent transmitter also leads to compatible satellite and terrestrial transmissions. A satellite could transmit across a region of the country with terrestrial re-broadcast transmitters on exactly

the same frequency being used to reinforce the signal in shadow areas. This feature may also allow a reduction in satellite power as primary satellite coverage would mainly need to serve open space.

79. The ability to support translators on the same frequency as the parent transmitter is an important feature of the Eureka 147 system for many countries. The transmitter power levels needed to provide adequate coverage at the L-band has not yet been fully determined. Present indications are that a six-channel system will require less power than a single channel transmitter for comparable coverage.

D. Systems being developed by the European Space Agency

80. Digital audio broadcasting is a new service that the European Space Agency (ESA) is investigating for future European satellite systems. ESA is actively promoting this service in their various mission options including non-geostationary satellite systems. One of the main technical challenges of this new service lies in the fact that the geostationary orbit is less suited for a large penetration of radio broadcasting services. ESA has therefore been looking with increasing interest to the exploitation of new orbit alternatives such as the circular low Earth orbit (LEO), the intermediate circular orbit (ICO) and the multi-regional highly inclined elliptical orbit (M-HEO). The utilization of these orbits poses several technical challenges. ESA's experimental programme called Archimedes will explore these challenges by flying one or more experimental satellites by 2000 that will be representative of future sound broadcasting and personal communication missions.

81. Systems based on circular orbits could provide global coverage but would require a fairly large constellation of satellites to do so. An alternative approach which would dramatically reduce the size of the required constellations, is based on the use of highly elliptical orbits (HEO). HEO constellations have been successfully used since 1966 in the former Soviet Union for community TV reception and emergency communications. More than 100 Molniya satellites (each with a relatively short operational lifetime) have been launched into elliptical, 12-hour orbits of the same name.

82. HEO constellations are well suited for regional or multi-regional services. A satellite in HEO lies in a plane that is inclined approximately 63 degrees with respect to the equatorial plane. This gives the satellite the advantage of being viewed at very high elevation angles in northern or southern regions. This compensates for the higher slant-range in comparison with LEO or ICO systems, and makes HEO satellites well suited for radio broadcasting in northern latitudes. It also allows high signal availability without penalizing the system economy by imposing large link margins. An advantage of using HEO satellites in northern latitudes is that when low-gain user-receiver antennas are used, as in the case of personal receivers, higher gain can be achieved (2-3 dB's more) compared with geostationary satellites.

83. In a HEO constellation the satellites are not stationary and are therefore used in the orbital arc around the apogee where they exhibit quasi-geostationary behaviour. The number of service areas is equal to the number of apogee points on the Earth ground track. HEO orbits with more than one coverage area are called multi-regional orbits. The number of satellites for a given constellation is determined by the number of service areas, multiplied by the orbital period, divided by the selected duration of the active arc.

84. Some broadcasters have expressed interest in satellite broadcasting, primarily because of the high availability rates and audio quality that HEO systems could provide. However, funding the development and launch of a full constellation of satellites is beyond their resources. Consumer electronics manufacturers are also interested in satellite radio but are clearly waiting for concrete implementation plans for the space segment before they commit resources to product development, manufacturing and marketing. Because of this widespread interest in satellite radio systems, and the reluctance to commit financial resources until the technology is fully proven, it is evident that the research and development funding and initial start-up costs

of an HEO or other type of constellation for satellite radio will have to come from the public sector. ESA's Archimedes programme will promote the possibilities of satellite communications.

85. In the framework of the Archimedes project, ESA is willing to pursue utilization of HEO constellations for multi-regional personal and sound broadcasting services. Over the course of the Archimedes programme ESA plans to target the development of an experimental satellite to demonstrate the viability of later operational systems.

86. Blockage of the satellite line-of-sight and multipath effects would degrade DAB services to a non-acceptable level. This is translated into the requirements of high elevation angles and high received power flux density over wide areas. The importance of satellite elevation angles has been demonstrated in several field measurement campaigns in the L- and S-bands. This problem is of particular relevance in all northern regions. A geostationary orbit-based service must include propagation margins in excess of 10 dB to serve those regions, which implies a design solution based on high-powered spacecraft with a large and complicated antenna system resulting in a high cost for telecommunication services.

87. ESA has studied the Tundra orbit, an elliptical orbit that has an orbital period of 24 hours and an inclination of 63.4° to the equatorial plane, as well as the Molniya orbit for coverage of Europe with high elevation angles. More recently, ESA has focused its attention on two types of Multi-regional Highly-Inclined Orbits (M-HEOs), the M-HEO(8) and M-HEO(16) orbits.

The M-HEO(8) system

88. The M-HEO(8) system being investigated by ESA is particularly well-suited to services such as personal communications and sound broadcasting. It would allow:

- a) High availability rates and continuous 24-hour service tailored to cover the three most important market areas of the world, i.e. Europe, Far East and North America; and
- b) The use of a minimum number of satellites for continuous coverage of these three service areas. The apogee at 26,000 km would allow power savings in comparison with other HEO alternatives or geostationary satellites. The lower apogee altitude M-HEO satellites would also offer a considerable advantage over the other HEOs in terms of orbit mass that can be delivered by a given launcher.

89. In its basic configuration, the M-HEO(8) system will be composed of a constellation of six satellites in 8-hour elliptical orbits. This six-satellite configuration would enable users to receive radio signals from satellites that would always be visible due to their high elevation angles. The coverage area of the M-HEO(8) system would include all of continental Europe where the minimum guaranteed elevation angle of more than 45 degrees would always be achieved. The other coverage areas are Japan, China, other parts of Asia, the Commonwealth of Independent States, Canada, the United States and Mexico, where elevation angles would always be greater than 40 degrees.

90. In its baseline configuration the M-HEO(8) system would provide integrated digital broadcasting services that would include the possibility of user interaction. Examples include:

- news and basic radio text;
- bilingual news and stereo music, basic radio text;
- multilingual news and hi-fi stereo music;
- multilingual news and CD stereo music, enhanced radio text or TV for pocket receivers;
- paging and messaging services;

- interactive services providing users with a low bit rate response channel. The maximum bit rate is around 50 bit/s;
- navigation services integrated with meteorological data broadcasting.

91. In order to deliver the necessary power flux density to provide these services to small receivers, multi-beam antenna coverage of the three service areas would be necessary. The M-HEO(3) coverage foresees the use of a reconfigurable antenna system providing five beam coverage (four spot beams and one global beam) in each service area. The four spot beams would be arranged in the three service zones in order to match linguistic and geographical constraints. The transponders are intended to provide a flexible share of resources according to market and user population needs. The transponder can be configured to provide a given distribution of services with different quality and power levels. It is fundamental that the selected modulation and multiplexing technique allows such flexible allocation of bandwidth and power resources. Approximately 1,000 watts of DC power will be allocated for the payload.

92. In order to simplify the design of the satellite, there will be no frequency reuse in a given service area, but in order to minimize the overall frequency requirements of the system, frequencies would be reused in different regions. The overall down-link frequency requirement will be roughly 10 MHz for operations in the three service areas. Due to the high elevation angles, frequency coordination would be simplified both with respect to geostationary satellites and terrestrial links.

93. The up-link of radio programmes would take place in a ground station equipped with 5 m tracking antennas. Each satellite will be tracked independently. A single up-link location above 58° N could address the European, Far Eastern and North American loops at the same time with a minimum satellite look-up angle of 5 degrees. Given that the up-link antennas would never cross the geostationary arc, the C-band can be used without the problem of coordination with respect to GEO satellites.

94. The sound broadcasting service is intended for a wide array of users in the three service areas. Users would be equipped with terminals that can be subdivided into three main classes:

- table-top radios equipped with directional antennas with adjustable elevation and azimuth controls;
- mobile receivers installed in moving vehicles with medium gain antennas with omni-azimuthal patterns;
- personal "walkman-type" receivers with low gain antennas with omni-azimuthal patterns.

E. INDOSTAR

95. The government of Indonesia has begun a programme for the development of social communication and education in which the country will become more industrially-oriented between 1994-1998. While emphasis on education has increased national literacy substantially, there are still many rural areas of the country where radio and television services, a principal and effective means of education and information dissemination, are not available.

96. The broadcasts of Radio Republic Indonesia (RRI) currently reach 67 per cent of the Indonesian archipelago and 80 per cent of its total population. The broadcasts of Television Republic Indonesia (TVRI) cover 37 per cent of the nation's territory and reach 68 per cent of the population. Nevertheless, there are still approximately 36 million Indonesians who are unable to receive RRI broadcasts and approximately 57 million Indonesians cannot receive TVRI. In addition to the coverage limitations experienced by the nation's principal broadcasters, studies have shown that an increasing number of foreign radio and television programmes have caused interest in locally-produced radio and television programmes to decline.

97. The Government of Indonesia therefore believes it is necessary for the country to develop a system capable of broadcasting high-quality radio and television programming to all its citizens. To accomplish this goal, Indonesia is investigating various transmission media through which it will be able to broadcast such programming to the largest number of people at the lowest possible cost to both the government and the people of Indonesia.

98. Distribution of radio and television programming is presently accomplished using several different transmission media. Telephone transmission circuits, designed primarily for voice circuits, not high fidelity radio, are often used for transmitting radio programming from one point to another due to the availability and extensive coverage of the telephone network. For several RRI stations, national programmes are relayed from Jakarta via short wave as the principle means of transmission. In some cases, programming received via short wave is then re-broadcast by a local medium wave transmitter, or received directly by listeners using short wave receivers.

99. Indonesia began the INDOSTAR project with the objective of improving the coverage, quality and affordability of broadcasting services within Indonesia. One of the goals of the programme is the development of an Indonesian direct broadcasting satellite (DBS). This DBS programme consolidates national broadcast requirements and services into a single cost-effective broadcast resource. The DBS system currently under development is being closely tailored for national coverage and programming requirements. Direct reception of both radio and television programming by the individual user in Indonesia, using low-cost receivers, directly from a standard quality broadcast coverage to the entire nation, is the fundamental goal on which the INDOSTAR programme is based.

100. The INDOSTAR system has been designed to take advantage of recently proven technology to provide excellent quality broadcast television and radio programming, simultaneously, to all of Indonesia. This programme, based on existing Lightsat technology, represents the most cost-effective method of delivering these services, while at the same time insuring quality broadcast reception. In addition to the advances made in Lightsat spacecraft technology, radio and television receiver technology is now taking advantage of recently pioneered digital processing, coding data compression and micro-electronics technology. These advances in receiver technology, coupled with a Lightsat satellite, provide the quality and quantity of services previously only available to the affluent, from very large satellites which typically cost three to four times what the INDOSTAR satellites are expected to cost.

101. The INDOSTAR DBS programme will provide both TV and radio broadcast services, direct from a geostationary satellite to TV-sets and radios without the need for expensive terrestrial re-broadcast stations for less than 10 per cent of the costs associated with short wave transmission operations, with substantially higher quality signals and complete national coverage. This programme is being developed as a "turnkey" project with launch of the INDOSTAR-1 satellite scheduled for mid-1995. The INDOSTAR system consists of three major elements: the Master Control Station (MCS), the INDOSTAR spacecraft and the ground segment. The MCS includes both a tracking, telemetry, control and monitoring facility, and a program uplink facility that will be used to collect, format and transmit radio and television programming to the satellite. The ground segment is comprised of three different types of receivers: two for TV reception and one for radio reception. Launch services, operation and management services, training, insurance and the development of in-country satellite TV and radio receiver manufacturing capabilities are also included in this broad programme.

102. The INDOSTAR radios are being designed to operate in any environment and will be capable of receiving digital audio broadcast from many satellites simultaneously without changing the antenna position or location. The INDOSTAR radio will be able to receive hundreds of radio channels in the future with quality varying from FM monaural to near CD-quality stereo. The INDOSTAR-1 satellite will broadcast up

to eight channels of varying quality radio programming. Additionally, INDOSTAR radios will be capable of receiving CD-quality terrestrial radio broadcasts broadcast via low power transmitters in major population centres, without requiring any modification or enhancement to the radio.

103. The satellite will receive transmitted programming signals and without modifying the signal, other than to change its frequency and boost its power level, re-transmit the programming signals towards the Earth in a "bent-pipe" fashion. The INDOSTAR satellites will broadcast radio programming in the L-band. Radio channels will be agile enough to allow the carriers to be moved to any location in the BSS-Sound band. This design characteristic supports mitigation of interfering signals. Through advanced data error correction and the use of data compression, the power flux density levels of the broadcasts arriving at the Earth's surface will be of such a level that they will not cause interference with any existing microwave of terrestrial land mobile systems in use today.

F. INTELSAT Digital Audio Distribution service

104. For nearly three decades, INTELSAT has worked closely with the world broadcast community to build a reliable and flexible international satellite system. The INTELSAT system provides coverage via its satellites over the Atlantic Ocean, Indian Ocean, Asia-Pacific and Pacific Ocean service regions to meet virtually every telecommunications need. For radio broadcasters interested in penetrating new markets, INTELSAT's Digital Audio Distribution (DAD) service can deliver high-quality radio programmes to any market in the world. DAD uses the latest in digital signal compression technology, and is intended to allow broadcasters to offer higher-quality, low-costs programming in order to increase listenership and profitability.

105. The DAD service is able to provide the following services to AM/FM stations with small C- or Ku-band antennas, international gateway earth stations or cable head-ends:

- digital distribution of audio for news, sports, music, talk programming and special events;
- point-to-multipoint distribution services worldwide;
- channel capacity provided at any data rate for any quality service (customers can set their own parameters). Audio quality available from CD quality channels (20 KHz) to nominal quality voice channels (5 KHz);
- full or fractional transponder leases;
- real-time transmission.

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